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Fostering the use of JANUS in operationally-relevant underwater applications

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Fostering the Use of JANUS in Operationally-Relevant Underwater Applications

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***Abstract*—This paper presents the use of JANUS in operationally-relevant underwater applications. JANUS is an open, simple and robust digital coding technology currently in process to become a NATO standard. Two underwater scenarios have been considered: 1) Broadcast of underwater AIS and situational awareness messages; 2) First contact and language switching. The JANUS physical coding scheme has been used by the underwater nodes as the common "language" to share data and to negotiate the switching into a different language, if needed. Field experiments have been conducted to test and validate the proposed approach. Different and heterogeneous configurations have been considered. In this paper we present the collected results and lessons learnt which are a promising starting point for fostering the research in this area.**

I. Introduction

The interest in Underwater Acoustic Networks (UANs) has significantly growth in the past decade. Novel protocols and increasingly reliable and robust communication technologies have been designed and implemented by academic institutions, research centres and industry. Unmanned maritime surface and sub-sea vehicles have more endurance, more capabilities and overall there are more to choose from.

These increasingly capable and complex networks are starting to be used in support of a wide range of emerging applications, including monitoring of the environment and of critical infrastructures, coastline protection, and prediction of underwater seismic and volcanic events [1], [2].

Although there have been significant progress and achievements in the area of UANs, there is still a main bottleneck which is imposing severe limits on how such networks are deployed: The lack of standards for underwater digital communication.

Several underwater digital modems are currently available on the market. None of these modems is, however, able to communicate with others produced by different manufacturers. Given the challenges imposed by the underwater acoustic channel, some of these modems implement physical modulation schemes that favour reliability instead of throughput. Others, tailored for specific operating conditions may be using an opposite approach. It's clear that there is no "one-fits-all" solution for underwater acoustic communications. The possibility of exploring different available solutions using a commonly agreed baseline standard would be very welcome.

To fill this gap, the NATO STO Centre for Maritime Research and Experimentation (CMRE) has been developing, testing and promoting, in collaboration with academia and industry, the creation of a robust and simple physical coding scheme to be used as the first standard for digital underwater communications. The proposed physical coding scheme, named JANUS [3], [4], [5], is currently going through STANAG (NATO Standardization Agreement) approval process. To promote the participation of industry and to make the standard usable and widely accepted, JANUS has been designed to minimise the changes required to bring existing underwater communications equipment into compliance. It is computationally simple, doesn't require power control nor flat frequency response in the transducers.

As for today, however, the use of JANUS in relevant underwater application scenarios has been very limited. A first attempt investigating and testing the use JANUS to implement a "bilingual" underwater acoustic modem is presented in [6]. The proposed solution was however not fully JANUS compliant since a different central frequency from that of the standard specification was used. In this work we extend what is presented in [6] to create a first contact and negotiation strategy in the underwater domain. Additionally, we show how JANUS can be a turnkey solution to increase the maritime awareness in a network of different devices with heterogeneous communication capabilities. Field experiments have been conducted in the Atlantic Ocean considering different and heterogeneous configurations. Positive results have been collected validating also the need for a solution like JANUS to be employed in real application scenarios.

The remainder of the paper is organised as follows: A description of JANUS is presented in Section II. In Section III we describe the considered application scenarios. Section IV presents the experimental activities and collected results. Finally, Section V concludes the paper.

II. JANUS

JANUS is a simple, robust signalling method for underwater communications that uses a coding scheme known as Frequency-Hopping (FH) Binary Frequency Shift Keying (BFSK) to transmit digital data as a sequence of short duration tones. It was developed at CMRE with the collaboration of academia, industry and government. The intention is for JANUS to become the standard of communication enabling interoperability between underwater NATO and NON-NATO, military and civilian maritime assets. The standard provides for a "baseline JANUS Packet" to be created (Figure 1), consisting of an acoustic waveform that encodes 64 bits of information (of which 34 bits may be user-defined according to their application). There is also the provision to seamlessly append “Cargo Data” to the end of the baseline JANUS packet. This approach provides almost unlimited flexibility in the nature and extent of the data to be sent.

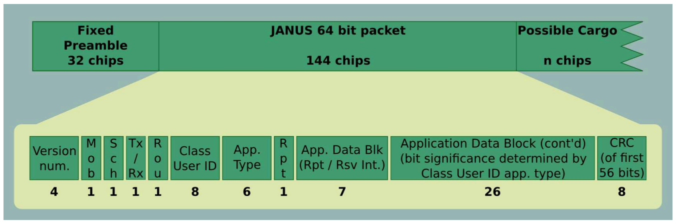

Figure 1: The structure of a JANUS packet

Following the standard design, the frequency band allocation is 9440 – 13600 Hz resulting in a bit rate of 80 bps. It’s important to note that these are the initial specifications. JANUS was designed to be scalable in frequency with all parameters being ratiometrically calculated from the centre frequency. Increasing the centre frequency will increase the bandwidth and provide higher data rates. This will be achieved at the price of shorter communication range (due to frequency dependent absorption) and lower link reliability (due to smaller chip time).

When considering JANUS to simply encode/decode arbitrary payloads, one may see this as similar to having an acoustic modem “talking” the JANUS language. JANUS however has been designed to be something more, aiming at defining a standard for underwater digital communication that can co-exist alongside proprietary solutions rather that trying to replace them. JANUS specifies not only the modulation and coding scheme but also the format of the information carried within the message. This makes it possible to correctly read and write the content of JANUS messages to and from any compliant transmitter and receiver. To support this capability and to enable a flexible development, the CMRE application layers using JANUS have been implemented using a plug-in approach. Different plug-ins can be designed to cope with the different nature and scope of the JANUS messages. To continue and foster the JANUS development, NATO has sponsored a NIAG (NATO Industrial Advisory Group) study on JANUS (NIAG SG190) with the objective of gathering insight from industrial players on aspects such as application scenarios, implementation guidelines, compliance and future protocol extensions. The sponsored study has highlighted how JANUS is a key solution to support a wide range of underwater applications which are relevant in the maritime domain, *e.g.* underwater digital emergency channel (similar to “Channel 16 VHF”), underwater Automatic Identification System (AIS), node discovery and negotiation, etc.

One of the activities of the NIAG SG190 has been the definition of JANUS use cases and scenarios. Suggestions for the content and format of the corresponding messages have been provided as well. In what follows we describe the considered application scenarios, the implemented JANUS plug-ins and the field experiments conducted to validate the proposed approaches.

III. Underwater Scenarios Considered

Given the JANUS robust design and low bit rate, it can be easily used has a common solution to increase the awareness of underwater assets about the presence of vessels in the area (Section III-A). Additionally, nodes can use JANUS to discover each other and to be informed about additional communication capabilities supported at each node. Nodes can then negotiate the switching to a “faster” and more performing modulation scheme for the exchanging of larger amounts of data (Section III-B).

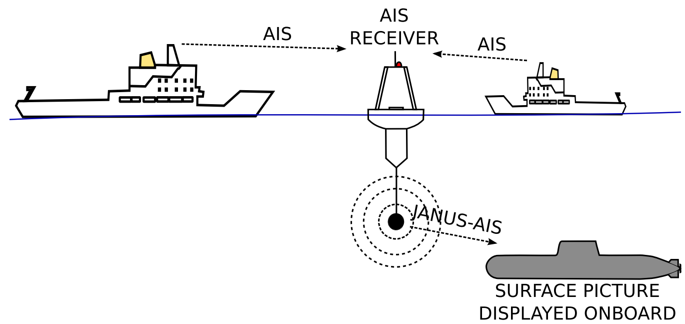

Figure 2: Underwater Broadcast of Situational Awareness Messages.

A. Underwater broadcasting of situational awareness messages

Increasing the maritime situation awareness is of key importance to improve navigation safety and to avoid possible incidents and collisions between surface and underwater assets. Figure 2 shows the considered application scenario where a surface node (In the drawing an unattended buoy), equipped with a AIS receiver, collects information about the surface assets operating in the area and it then broadcast the collected data to the underwater nodes. Since the surface station does not know what kind of devices are operating underwater and what acoustic modem they support, the use of a common “language” is mandatory. The same approach can be applied to inform a surface station about the presence of underwater devices. Additionally, radar/sonar and other approaches can be combined with AIS data[1] for the detection of assets that are not broadcasting AIS data.

B. First contact and language switching

In order to accomplish challenging cooperative tasks it is important to support the interaction and cooperation of multiple surface and underwater assets, which may be equipped with heterogeneous communication capabilities. There is therefore the need to use a common language to implement a

[1] Data fusion of different sources of information is outside the scope of this paper.

discovery procedure and to share the communication capabilities supported by each node (Figure 3). Knowing what nodes are in the area and what they can do would allow network operations to be optimised and to make better use of the underwater medium and node capabilities.

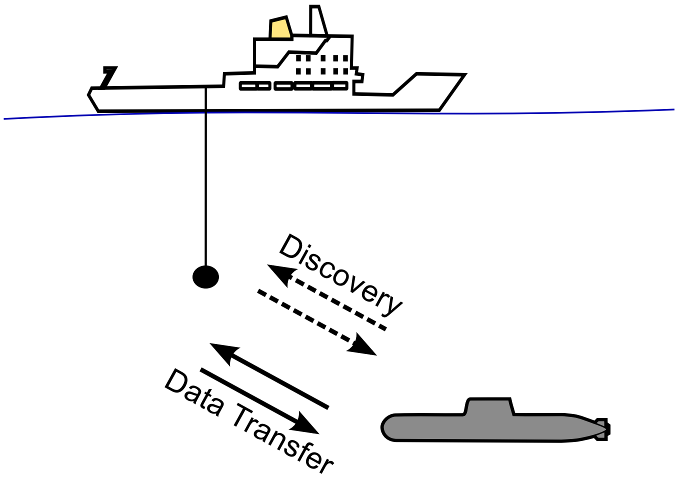

Figure 3: First Contact and Language Switching.

JANUS perfectly responds to this need. It offers a robust modulation scheme that can be used to negotiate the establishment of a different communication method, better suited to the considered scenario. Different communication strategies and protocol solutions can be negotiated based on the system requirements, network conditions and node capabilities.

IV. Experimental Setting and Results

In order to implement and test the designed solution, we have extended the JANUS software that is freely available from the JANUS wiki web page [7]. Novel JANUS plug-ins have been designed and integrated in the overall JANUS code, considering the NIAG SG190 suggestions. The implemented solution has been tested and validated during the REP15-Atlantic experiments, conducted in cooperation with the Portuguese (PRT) Navy and the Universities of Porto and Azores. The activity took place off the coast of Faial island, in the Azores archipelago, Portugal, in July 2015. The two application scenarios described above have been addressed considering multiple surface and underwater assets. These particular tests took place during several days of the experiment.

A. Broadcasting of situational awareness messages

For this test (Figure 4), a dedicated AIS receiver was installed in the research vessel (PRT Navy's NRP Gago Coutinho) form which the experiments were conducted. The vessel also hosted the experiment Control Station (CS). The acoustic transducer, connected to the CS, was deployed off the ship at a depth of $\sim$ 20m. The CS collected AIS data and periodically broadcasted it in the form of situational awareness messages in the underwater channel. An acoustic receiver

Figure 4: Underwater Broadcast of Situational Awareness Messages - Node locations.

(Gateway Buoy) was deployed at $\sim$ 20m listening to the channel to collect the transmitted information.

The two nodes were placed at different testing distances (600m and 1000m). The CS was configured to consider only AIS contacts within a radius of 4 and 8 kilometres. The detected number of contacts ranged between 0 and 3 with an average value of 2.4 contacts for each set of transmissions. Two different approaches have been used: 1) Transmitting the intended information using multiple short baseline JANUS packets (as proposed in the NIAG study); 2) Using one longer JANUS packet with cargo data. When using one single longer packet the channel is kept continuously busy for a longer time, additionally a CRC for the cargo data has to be added. When using only baseline JANUS packets, each packet stays on the channel for a short time. Each packet has however only 34 bits available for user data and multiple of these packets have to be transmitted. Additionally, splitting the payload over multiple packets introduces packet dependencies. If some of these messages get lost it is possible that part of the received packets become useless. Using 372 bits to encode the required data to transmit for the broadcasting platform and 3 detected contacts[2] 11 baseline JANUS packets are needed for a total of 704 bits transmitted in water. Using the cargo data only 452 bits are needed (including baseline packet information and CRC), thus reducing the introduced overhead by 64%.

Table I: Situational Awareness Messages Results

Tx strategy	**Overhead**	**BDER**
Baseline JANUS packets	$\sim$ 109%	0.2
Baseline JANUS packets with cargo data	$\sim$ 28%	0.16

[2]For the broadcasting platform and for each contact the transmission includes the type of the asset (ship, submarine, etc.), the navigation status (at anchor, under way using engine, not under command, etc.), speed, course, depth, GPS.

To investigate the performance of these two approaches under similar channel conditions, we first used the sequence of short JANUS messages to transmit the intended data and we then appended the packet with cargo data at the end of the sequence. Over the different tests, more than 800 JANUS packets were transmitted (90% short baseline packets and 10% with cargo data). Table I shows the obtained results. For each strategy we present the introduced overhead (expressed as the percentage of total bits transmitted with respect to the actual payload) and the experienced Bit Delivery Error Rate (BDER). The BDER is defined as the ratio between bits lost and the bits generated by a node (at the application level). We can clearly see that when a large amount of data needs to be transmitted, the use of cargo data is a feasible solution. It reduces the overhead at the price of keeping the channel continuously busy for a longer time. JANUS is, however, a robust modulation scheme that can cope with long packet transmissions. By reducing the overhead and the number of required packet transmissions/receptions, less detection and synchronization operations are required at the receiver, which for a stable channel, will result in a reduced BDER. Given the packet dependency when using multiple short messages to encode the full payload, in some case key packets were lost and the receiver was not able to reconstruct the full message. The use of cargo data resulted therefore in a probability to decode the transmitted message 10% higher.

B. *First contact and language switching*

To implement this application scenario, an handshaking approach (request/response) has been considered. For the discovery of a neighbour node and of its communication capabilities and for the negotiation of the language to use. Given the small amount of data to transmit only baseline JANUS packets can be used. We have considered a language selection policy switching from JANUS to any language with a faster (higher bit rate) transmission capability. All the retransmission and recovery strategies to cope with errors and packet losses have been implemented.

Two nodes have been employed during the tests. One connected to the CS equipped with JANUS, Evologics modem [8] and a FreeWave radio antenna. A second portable node supporting JANUS and interfacing an Evologics modem. The Evologics S2C R18/34 acoustic modem provides the possibility to transmit with a rate of 480 bps while the JANUS transmission rate is 80 bps.

In total, 830 baseline JANUS packets were transmitted over the different days of testing. Table II summarises the percentage of packets transmitted for each of the different message handshakes and the measured bit delivery error rates (BDER).

After the nodes discovered each other, they negotiated a switch to the Evologics language (the only faster language they had in common) to transmit a large amount of data at a higher speed. After that they reverted back to JANUS for further discovery and negotiation. After switching to Evologics, 1927 packets ($\sim$ 73KB) were correctly delivered between the two nodes using a transmission rate approximately six times faster. It was observed during the negotiation phase that in some occasions, node response packets were lost (17% of the switch over responses were lost). This resulted in having the two nodes using different languages for some time before going back to JANUS via a built-in timeout mechanism. More robust and sophisticated language selection policies and negotiation strategies need to be explored to make the whole procedure more reliable and efficient.

Table II: First Contact and Language Switching Results

Message type	**Percentage of packets per handshaking type**	**BDER**
Node discovery handshake	23%	0.30
Comms capability handshake	42%	0.28
Language switching handshake	35%	0.33

V. Conclusions

In this paper we have investigated the use of JANUS in two highly relevant underwater application scenarios. We have shown how JANUS can be used as a feasible solution to increase the maritime situational awareness in the underwater domain, reducing the risk of collisions involving underwater assets. Additionally, we have demonstrated how JANUS can be used to initially share contact and communication capability in a heterogeneous network and to then switch to a different and more capable language for faster data transmission. Novel policies and strategies have to be investigated addressing: How to select the best language to use, what information to use to take the decision, how long to stay on the selected language, how to make a cooperative and coordinate switch over that involves more than two nodes, etc.

The use of a standard, commonly agreed "language" for underwater digital communications is a long overdue key enabler of cooperation among heterogeneous underwater assets. Fostering the use of JANUS in relevant application scenarios is a key challenge towards a better and more efficient use of underwater networks.

Acknowledgments

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REFERENCES

[1] J. Heidemann, M. Stojanovic, and M. Zorzi, "Underwater sensor networks: Applications, advances, and challenges," *Royal Society*, vol. 370, no. 1958, pp. 158–175, May 2012.

[2] L. Lanbo, Z. Shengli, and C. Jun-Hong, "Prospects and problems of wireless communication for underwater sensor networks," *Wireless Communications and Mobile Computing, Special Issue on Underwater Sensor Networks*, vol. 8, no. 8, pp. 977–994, August 2008.

[3] K. McCoy, "JANUS: From Primitive Signal to Orthodox Networks," in *Proceedings of the 3rd International Conference and Exhibition on Underwater Acoustic Measurements: Technologies & Results*, ser. UAM2009, Nafplion, Greece, June 21–26 2009.

[4] K. McCoy, B. Tomasi, and G. Zappa, "JANUS: The genesis, propagation and use of an underwater standard," in *Proceedings of the European Conference on Underwater Acoustics*, ser. ECUA2010, Istanbul, Turkey, July 5–9 2010.

[5] J. R. Potter, J. Alves, D. Green, G. Zappa, I. Nissen, and K. McCoy, "The JANUS Underwater Communications Standard," in *Proceedings of IEEE UComms 2014*, Sestri Levante, Italy, September, 3–5 2014.

[6] R. Petroccia, G. Cario, M. Lupia, V. Djapic, and C. Petrioli, "First in-field Experiments with a "Bilingual" Underwater Acoustic Modem supporting the JANUS Standard," in *Proceedings of MTS/IEEE OCEANS 2015*, May 18–21 2015.

[7] "JANUS wiki," Last time accessed: March 2015. [Online]. Available: http://www.januswiki.org/tiki-index.php

[8] Evologics, "Evologics S2C acoustic modems," Last time accessed: September 2015. [Online]. Available: http://www.evologics.de/

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